low-power solid state components such as computer chips, or can weaken them to the point that they fail months after a lightening event.

Not every lightning strike is damaging. The amount of damage depends on the amount of current in the return stroke, the magnitude of any continuing current, and the susceptibility of the target to lightning damage. Electronic equipment, for example, is more susceptible to failure from a lightning strike than a concrete pad is to fire damage. The main danger to a site from lightning is from fire, as fire can potentially lead to a release of radioactive or chemically hazardous material. Lightning-induced fire can be caused in several ways. Examples are listed below.

- Fire can be started in dry combustible material such as a wooden structure or dry grass by the weak "continuing current" between lightning strokes. About 20 percent of lightning strikes have a continuing current large enough to start such a fire.[28] The magnitude of the peak current is not relevant here, as the return stroke is too brief to start a fire. For lightning to start a range fire, the range grass has to be dry. It is unlikely, therefore, that a range fire would start during a rainstorm.

- A lightning strike on a building can induce large currents in the electrical wiring in the building. It is possible that the high current will cause a breakdown in both the insulation on the wiring and the insulation provided by the air, causing an electrical arc to form between the wire and a nearby grounded object. A follow-on current from the electrical circuit would then sustain the arc and could continue for many seconds or even minutes, long after the lightning strike is gone. Combustible material in the immediate vicinity could then be ignited. Although arcing is more likely with larger-current strikes, any magnitude of strike could produce it. To be conservative, all lightning strikes on a building should be considered.

- A lightning-induced spark in the building could ignite volatile gases from rags damp with cleaning fluids. This could occur with a lightning strike of any magnitude current.

Damage to electronic components from lightning strikes generally can be ignored for safety analyses because such damage is usually not associated with the release of radioactive or chemically hazardous materials.

9.5 DEEP-BED SAND FILTERS

Deep-bed sand (DBS) filters have been used in the ventilation and process exhaust systems of radiochemical processing facilities since 1948. The major attractions of DBS filters include large dust-holding capacity, low maintenance requirements, inertness to chemical attack, high heat capacity, fire resistance, and the ability to withstand shock loadings and large changes in air stream pressure without becoming inoperative. The disadvantages of DBS filters include high capital cost; large area; high pressure drop and power cost; uncertainties in selection, availability, grading, and handling of suitable sands; and issues with disposal of the spent unit.

DBS filters are deep (several feet thick) beds of rock, gravel, and sand, constructed in layers graded with about two-to-one variation in granule size from layer to layer. Airflow direction is upward, and granules decrease in size in the direction of airflow. A top layer of moderately coarse sand is generally added to prevent fluidization of finer sand. The rock, gravel, and sand layers are positioned and sized for structural strength, cleaning ability, dirt-holding capacity, and long life. A cross-section of a typical DBS filter is shown in **FIGURE 9.21**. Ideally, the layers of larger granules, through which the gas stream passes first, remove most of the larger particles and particulate mass, and the layers of finer sands provide high-efficiency removal. Below the fixed bed of sand and gravel is a course of hollow tile that forms the air distribution passages. The filter is enclosed in a concrete-lined pit. The superficial velocity is around 5 fpm, and the pressure drop across seven layers, sized from 3 1/2 in. to 50 mesh, is from 7 to 11 in.wg. Collection efficiencies up to 99.98 percent [determined by in-place test with polydisperse 0.7-number medium diameter (NMD) test aerosol have been reported.[33] The approximate capital cost of a sand filter is $300 per cfm in 2001 dollars.

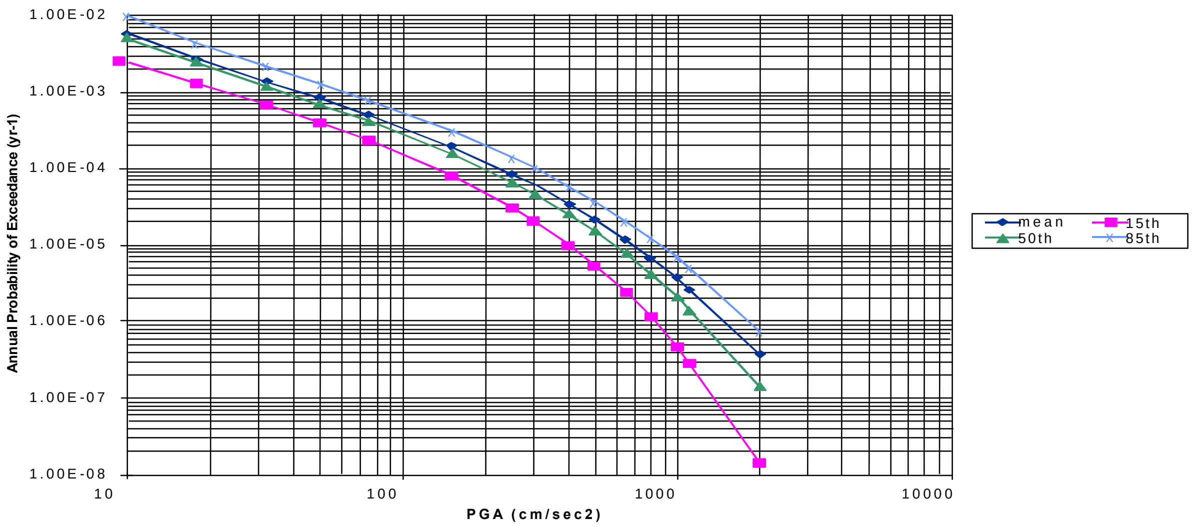

Figure 9.21 – Seismic hazard curves for Pantex soil site

A removal efficiency approaching that of a single HEPA filter is claimed for DBS filters if the proper sands are used and the contact path is long enough. Efficiency tests of DBS filters are conducted using polydispersed test aerosols with an NMD of about 0.7 μm and the in-place test procedures described in Chapter 8. True efficiency tests of HEPA filters, on the other hand, are made with a monodispersed test aerosol with an NMD of 0.3 μm. In addition, tests of very large units such as DBS filters are often made under conditions that sometimes yield results that are difficult to interpret. For these reasons, although the efficiency of DBS filters approaches that of HEPA filters, it cannot be assumed that the efficiency of DBS filters for submicron particles is actually equivalent to that of HEPA filters.

DBS filters have received renewed interest in the past few years because of increased concern about the effects of natural phenomena (earthquake, tornado), fire, and explosion, and because procurement and maintenance costs of alternative air cleaning methods have increased substantially. DBS filters are characteristically one-of-a-kind designs. They are literally constructed in the field as the gravel is positioned and the sand is poured in place. A view of a DBS filter under construction is shown in **FIGURE 9.22**. No standards exist, so most of the information for new designs must come from reports of previous applications. A bibliography and review of DBS filters built prior to 1970 was prepared by Argonne National Laboratory.[32]

Following initial installation of a DBS filter at DOE's Hanford site, nine others were installed at Hanford, Savannah River, and the Midwest Fuel Recovery Plant at Morris, Illinois. All but one[33] of these were designed for cleaning ventilation air from fuel reprocessing facilities, and only four (all at Savannah River) are currently used for this purpose. There is a DBS filter in the roof of the Zero Power Research Reactor[47] at Idaho Falls, but it is for emergency exhaust cleanup only and is not operated under normal conditions. Details of existing U.S. DBS filters are given in **TABLE 9.5**. Properties of sands and aggregates used as the filtration media of these filters are given in **TABLE 9.6**.

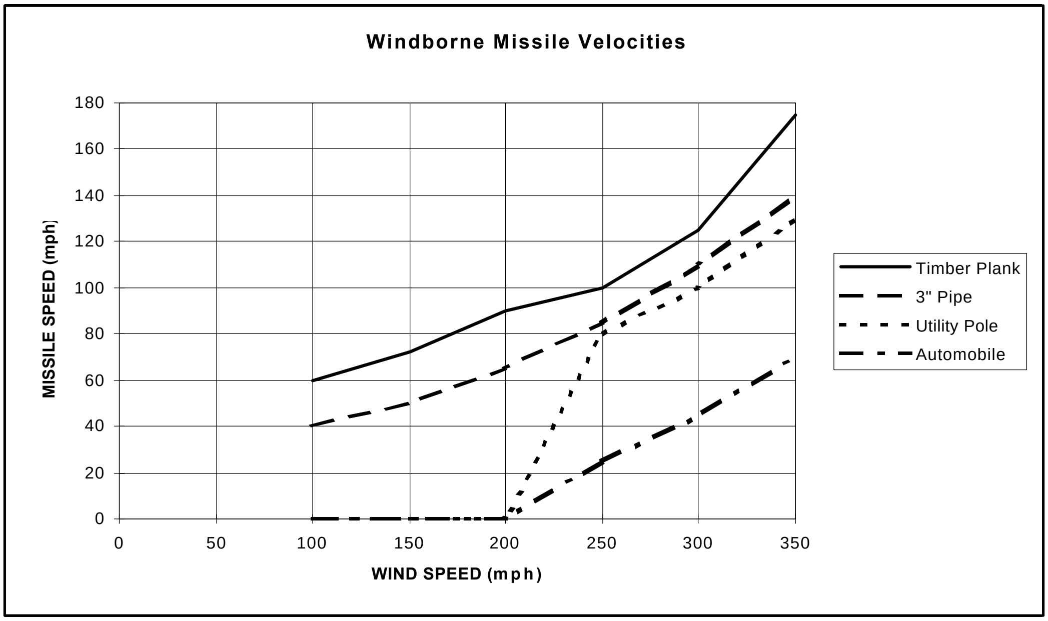

Figure 9.22– Windborne missile velocities versus wind speed

Table 9.5 – Dimensioons and Operating Data of Existing U.S. Deep-Bed Sand Filters

DBS Filter No.[a]	Plan dimensions[b] (ft)	Design flow (cfm)	Design superficial velocity (fpm)	Design pressure drop (in.wg)	Date of initial operation	Present status of DBS
1	108×46	25,000	5.0	5.0	1948	Standby
2	108×46	25,000	5.0	7.0	1948	Standby
3	96×96	40,000	4.3	10.0	1950	*c*
4	85×85	40,000	5.5	12.0	1951	Active
5	240×100	115,000	4.8	~10.0[c]	1954	Standby
6	240×100	115,000	4.8	9.2[c]	1955	Standby
7	360×100	210,000	5.8		1975	Active
8	360×100	210,000	5.8		1976	Active
9	140×103	74,000	5.1		1974	Active
10	72×78	32,000	5.7		1974	*d*
11	50 to 62.5 (diam)	*E*	*e*		1968	Active

[a]Filter identification:

1. T Plant, Building 291-T, Hanford West Area, Richland, WA.
2. B Plant, Building 291-B, Hanford East Area, Richland, WA.
3. U Plant, Building 291-U, Hanford, Richland, WA.
4. Redox Facility, Building 291-S, Hanford, Richland, WA.
5. F Area, Building 294-F (old), Savannah River Plant, Aiken, SC.
6. H Area, Building 294-H (old), Savannah River Plant, Aiken, SC.
7. F Area, Building 294-1F (new), Savannah River Plant, Aiken, SC.
8. H Area, Building 294-1H (new), Savannah River Plant, Aiken, SC.
9. SRL, Building 794-A, Savannah River Laboratory, Aiken, SC.
10. Midwest Fuel Recovery Plant (MFRP), Morris, IL.
11. Zero Power Plutonium Rector Facility, Argonne National Laboratory, Idaho Falls, ID.

[b]Inlet side shown first, outlet side italicized.

[c]Unit in service, process operation was discontinued in 1975.

[d]MFRP is not engaged in reprocessing, only storage; sand filter is active.

[e]This is an emergency relief system.

Table 9.6 – Properties of Sands and Aggregates used in existing U.S. Deep-bed Sand Filters

PROPERTY	**FILTER NO.**[A]									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Depth of bed, ft	9	8.5	8	8	8	8	7.5	7.5	7.5	8
Number of layers	9	8	7	7	7	7	6	6	6	
Depth of layers (in.)										
Granule size range, mesh (unless in. noted)										
Layer A 3-2 in.	12									
2 1/2-1 1/4 in.		12								
3-1 1/4 in.					12	12	12	12	12	
3-1 in.			12	12						18
Layer B 2-1 in.	12									
1 3/4-5/8 in.		12	12	12						12
1 1/2-5/8 in.					12	12	12	12	12	
Layer C 1-1/2 in.	12									
3/4 in. ~ 6		12	12	12						
5/8-1/4 in.					12	12	12	12	12	
Layer D 1/2 in.-4	12									
3/8 in.-3										12
Layer E 4-8	12	6	6	6	6	6	6	6		6
1/4 in. - 8									6	
Layer F 8-20	12	12	12		12	12	12	12	12	6
8-18				12						
Layer G 20-40										
30-50					36[c]	36	36	36	36	
20-50			36	36[c]						36

[a]See TABLE 9.5 for locations corresponding to number.
[b]Cable and wire mesh of footnote a catenary cross-section support, deep bed.
[c]Removed 12 in. from G layer, July 1972, to reduce pressure drop.

9.5.1 Deep-Bed Sand Filters Design

A rough approximation of the collection efficiency of sand, on an activity basis, is given by the following equation:[48]

$$\text{ç} = -\exp(-KL^{1,2}V^{-1,3}D^{-4,3}),$$

where

ç = fractional collection efficiency on a radioactivity or mass basis;

L = depth of fine sand, ft;

V = superficial gas velocity, fpm;

D = average sand grain diameter, in;

K = proportionality factor.

[Note: The values of L, V, and D vary with sands from different sources of the same mesh size and must be determined experimentally for any given sand.]

Values for the proportionality constant, *K,* for several sands tested at Hanford are:

Type of sand	**K**
Hanford	0.053
AGS flint	0.045
Rounded grain sand (Ottawa, Eau Claire, Monterey)	0.035

Collection efficiency on a radioactivity basis gives a higher number than the collection efficiency on a count basis, as reflected by the test aerosol test, because larger, more easily collected particles may carry more radioactivity and bias the analysis to give greater value to larger particles. The relationship between count and activity collection efficiency cannot be determined without accurate information on aerosol size distribution and the relationship of aerosol size to radioactivity.

The approximate void fraction of a sand bed is generally about 0.4. Sand permeability tests have shown that intense vibration can cause extreme compaction, resulting in near doubling of the pressure drop.[49, 53, 54] Factors that must be considered include the effects of compaction, steam injection, relative humidity, and velocity change on efficiency and pressure drop. Besides permeability and filtration requirements, the sand must be abrasion- and fracture-resistant and must resist corrosion from the fumes likely to be present in the exhaust air stream.

Filter life is determined by the increase in pressure drop and the decrease in gas flow caused by the collection of solids within the sand bed. Filter life can be significantly reduced if solids collection is concentrated in small fractions of the bed or on the finer sand. Uniform concentration of coarse aggregate layers upstream of the fine sand layer tends to maximize filter life.

Clogging of DBS filters is aggravated by local decreases in porosity at the interfaces between graded layers. The mixing of aggregates (sand, gravel) at the interfaces usually results in a lower void fraction at the interface than if no mixing is permitted. The extent of reduction in void fraction depends on the characteristics of the aggregates and on the technique used to charge them into the filter bed. The lowest layer may require hand placement for the first few inches so that no rocks fall through the openings in the distribution blocks. Significant improvement in filter life can be obtained by careful attention to loading.

The DBS filter housing is a poured concrete structure, located partially underground, with walls capable of withstanding the DBE without cracking and the design basis flood without leaking. The floor has channels for distributing the incoming air and is covered by the special hollow block shown in the view of an empty DBS filter. The floor and the distribution system must bear the weight of the sand column above it. With corrosion and aging, withstanding this weight has been a problem in some DBS filters. The floor should be sloped to a drain and have a built-in capability for drainage if it becomes necessary. It is often prudent not to connect the drain line so that a determination of what to do with the drainage can be made after the event if flooding occurs. The filter should be on the suction side of the fan so that it is negative to the atmosphere and all leakage is inward.

When a DBS filter is used in series with HEPA filters, it should be located upstream of the HEPA filters. In this position, the high dust-holding, fire-resistance, and pressure-surge-attenuating characteristics of the DBS filter can protect the HEPA filters that provide the final containment barrier.

9.5.2 DEEP-BED SAND FILTERS PLUGGING

Some filters have experienced plugging at low dust loadings. In one case, the plugging was caused by moisture entering through cracks in the concrete sidewalls of the unit.[56] In another instance, plugging was caused by crystal growth in the filter media fines, probably due to a reaction of nitric acid vapors from the process building with calcite, with dolomite present in the original sand, and with cement dust generated by severe erosion and acid attack on the concrete entry ducts and support structures.

9.5.3 SPENT MEDIA DISPOSAL

Deactivation of existing filters is generally accomplished by scaling and abandoning the filter. Spent media are stored in place within the unit. The total unit is replaced by a new filter located close by. Present government regulations for radioactive solid waste, though unclear, may rule out such in-place disposal in the future. If the material were handled as high-level radioactive waste, each 1,000-cfm capacity of filter would require about two hundred 55-gallon drums for disposal. A detailed analysis of filter decommissioning was performed for the PDCF Project at the Savannah River Site. This is currently the best available information on the cost of decommissioning.

9.5.3.1 Burial in Place

Burial in place (or entombment) for DBS filters is feasible and could be economical if provisions are applied during initial design of the filters to ensure that the walls, floors, and roof integrity are sufficient to satisfy the requirements of 10 CFR 61,[36] and the requirements of other regulatory agencies such as the U.S. Environmental Protection Agency and SCDHEC. To ensure that the selected location of the DBS filter can be licensed, the location must be suitable for near surface disposal in accordance with 10 CFR 61, Subpart D.[36] The primary emphasis in disposal site suitability is given to isolation of the waste. This involves evaluation of long-term impacts and disposal site features that ensure that the long-term performance objectives of 10 CFR 61, Subpart C,[36] are achieved.

To ensure that the facility can be licensed as a near-surface land disposal facility, initial site characterization and the installation of long-term ground water monitoring wells during construction is essential. Estimated costs associated with this method of disposition are provided in **TABLE 9-7**.

Table 9-7
DBS Filter Entombment Decontamination and Decommissioning Cost Estimate*

Cost Parameter	Unit Cost/ ft³	Volume, ft³	Total Cost
Licensing			$500,000
Initial Site Characterization			$200,000
Monitoring Well			$100,000
Grout void space	$5.00	144,000	$720,000
Cover Fill (5 m) (Ref. 6.4)	$0.50	590,400	$295,200
Tunnel Decon			2,073,474
		Total	$3,888,674

* Assume the void space above the fill to be 4 ft high, 300 ft wide, and 120 ft long, with a volume of 144,000 ft^3.

9.5.3.2 Decontamination

Because of the irregular surface areas and porous nature of the clay tile, stones, gravel, and sand filter media utilized in DBS filters, decontamination methods currently available would be mostly ineffective. Ancillary materials such as concrete containment walls and supports and steel grating, if utilized, are potential candidates for decontamination, but make up a relatively small percentage of the total mass of the DBS filter.

9.5.3.3 Onsite Disposal

Low-level waste onsite disposal techniques include:

- Onsite transport in steel containers from point of origin to storage vaults
- Manual sorting of waste to separate out compactable waste
- 55-gallon drum compaction, when practical
- Return to steel containers
- Final interment in the waste storage vaults

On-site disposal techniques are well developed and currently licensed. However, existing permits limit current space availability. **TABLE 9-8** provides a cost estimate for on-site disposal of filter materials and stabilization by grout of the remaining structural members.

Table 9-8
Sand Filter On-Site Disposal Cost Estimates

Without Characterization					
Activity		**Volume (ft^3)**		**Cost/ft^3**	**Cost $**
Filter Media Disposal		288,000 ft^3		$106	$30,528,000
Activity	**Volume (ft^3)**	**Hr/ft^3**	**Cost/ft^3**	**Labor $/hr**	
Media Removal	288,000	0.10		$57.76	$1,663,488
Grout Fill	432,000		$5.00		$2,160,000
Tunnel Decon					2,073,474
				Total	$34,351,488
With Characterization					
Activity		**Volume**		**Cost/ft^3**	**Cost $**
Filter Media Disposal		144,000 ft^3		$106	$15,264,000
Activity	**Volume (ft^3)**	**Hr/ft^3**	**Cost/ft^3**	**Labor $/hr**	
Media Removal	288,000	0.10		$57.76	$1,663,488
Characterization	288,000	0.05		$83.09	$1,196,496
Grout Fill	432,000		$5.00		$2,160,000
Tunnel Decon					2,073,474
				Total	$20,283,984

Sand Filter Specifications:

Required Flow	Velocity	Face	Length	Width	Depth
160,000 cfm	5 fpm	32,000 ft^2	300 ft	120 ft	8 ft
Waste Volume		Face			
288,000 ft^3		36,000 ft^2			

9.5.3.4 OFFSITE DISPOSAL

An alternative approach would be for removal of filter media from the sand filter structure and disposal at an offsite near-surface land disposal site such as in Barnwell, South Carolina. Offsite disposal methodologies would be similar to on-site disposal impacts, except that the increased costs of offsite burial would be incurred. Labor costs for offsite disposal would be similar to those incurred for on-site disposal. Current disposal costs at the Barnwell facility are about $570 per ft^3. **Table 9-9** provides a cost estimate for offsite disposal of filter media and stabilization by grout of remaining structural members.

9.5.3.5 LONG-TERM SAFE STORAGE

This approach requires continuing surveillance and security measures to prevent inadvertent intrusion. While costs may not be severe on an annual basis, in the long term they can be significant. This alternative constitutes a continuing threat to the public and the environment. Ultimate disposal would still be necessary, but at escalated costs.

Table 9-9 Sand Filter Offsite Disposal Cost Estimates					
Without Characterization					
Activity		**Volume (ft³)**		**Cost/ft³**	**Cost $**
Filter Media Disposal		288,000		$570	$164,160,000
Activity	**Volume (ft³)**	**Hr/ft³**	**Cost/ft³**	**Labor $/hr**	
Media Removal	288,000	0.10		$57.76	$1,663,488
Grout Fill	432,000		$5.00		$2,160,000
Tunnel Decon					2,073,474
				Total	$167,983,488
With Characterization					
Activity		**Volume**		**Cost per ft³**	**Cost $**
Filter Media Disposal		144,000		$570	$82,080,000
Activity	**Volume (ft³)**	**hr/ft³**	**Cost/ft³**	**Labor $/hr**	
Media Removal	288,000	0.10		$57.76	$1,663,488
Characterization	288,000	0.05		$83.09	$1,196,496
Grout Fill	432,000		$5.00		$2,160,000
Tunnel Decon					2,073,474
				Total	$87,099,984